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CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

LI. — A METHOD OF DETERMINING THERMAL CONDUCTIVITY.

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Presented December 13, 1905. Received December 15, 1905.

Among the various methods for determining thermal conductivity, the wall method, a modification of which is here employed, has been perhaps most frequently used. It has been open to the serious objection that the temperatures of the surfaces of the metal may not be the same as those of the heating and cooling baths which have frequently been taken as the temperatures of the metal surfaces. This difficulty was overcome by Professor E. H. Hall by plating the surfaces of the wall with another metal and using the E. M. F. of the thermo-electric junctions so formed to determine the temperature difference. There are also difficulties in insuring a perfectly uniform flow throughout the section under investigation.

The method here employed is to liberate electrically a known quantity of heat inside a spherical shell of the substance, and maintain the outside surface at a constant temperature. The difference of temperature thus produced is measured by means of thermo-electric junctions of which one metal is that of the shell, the other metal being electroplated upon it. This method, then, will insure (1) uniform flow of heat, (2) absence of radiation corrections, (3) exact determination of the temperature difference, (4) an exact determination of the quantity of heat passing through the wall, and (5) independence of the density and specific heat of the substance.

Let the quantity of heat be represented by Q; the difference of temperature of the surfaces of the shell by $t_1 - t_2$; the radii of the shell by p_2 and p_1.

Then

$$K = \frac{Q(p_2 - p_1)}{4\pi(t_1 - t_2)p_1 p_2}$$

DESCRIPTION OF APPARATUS.

The shell is in the form of a hollow sphere of cast iron, in the casting of which every precaution was taken to have the iron free from blow holes and of uniform quality. It is divided into two hemispheres by a plane passing through a great circle. A narrow rim on one hemisphere accurately fitting a corresponding groove in the other, insures the perfectly concentric position of the two parts at all times. A radial hole is provided for the admission of lead wires to the heating coil and thermo-electric junctions, and another for the shaft which drives the fans in the interior of the sphere.

The sphere is coated by electrolysis with copper to a uniform thickness of about 2 mm., it having been shown by Professor Hall[1] that this thickness would be sufficient to prevent the lead wires from conducting away sufficient heat to change the temperature in the immediate vicinity of the copper-iron junction.

These lead wires, eight in number, four inside and four outside, are electroplated to the copper. The two from the inside of each hemisphere are brought through a wood fibre plug split in the same plane as the sphere. These are then united with the outside wires, and the whole wrapped with a thin silk ribbon, thus forming a small, well protected cable. The ends of the wires are brought to a block of fibre $3'' \times 1'' \times \frac{5}{8}''$ provided with eight small holes arranged in two rows $\frac{1}{2}''$ apart. The wires from the outside are put in one row, and the corresponding ones from the inside in the other. The holes are then filled with mercury and a cover of fibre with a similar set of holes screwed on the block to hold the wires in place.

The leads from the galvanometer are brought to this block and so arranged that any pair of junctions can be connected and reversed without approaching the block or galvanometer. The D'Arsonval galvanometer used has a resistance of about 600 ohms and gives a deflection of about 160.0 mm., readable to tenths of a mm., with a potential difference of .0001 volt, the scale distance being 3.3 meters. It is mounted on a Julius device and carefully protected from mechanical disturbances. The galvanometer and leads to the junctions are packed in hair felt to insure a constant temperature.

The temperature of one of the junctions must be known. This is accomplished by means of a thermo-electric couple consisting of an iron and a nickel wire. One junction is fastened securely in a wood fibre plug so that it makes contact with the material of the sphere exactly where the copper joins the iron on the outside. The other junction is placed in a large beaker of oil. The iron wire is cut, and from its terminals, leads taken to a sensitive galvanometer. The beaker is heated until there is no deflection of the galvanometer, and the temperature read by means of a thermometer. The bath is heated slowly and stirred vigorously to insure uniformity of temperature and reduce the effect of the lag in the thermometer.

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[1] These Proceedings, **31**, 1895.

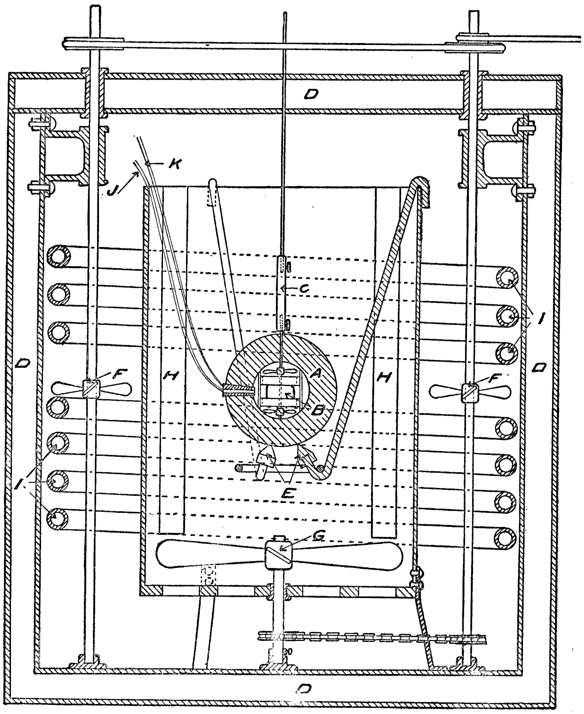

Figure 1.

The interior of the sphere is filled with oil. The heat is produced by means of an electric heating coil. This coil is made of No. 28 (B. & S.) German silver wire, having a resistance of about 13 ohms. It is wound upon two rings of wood fibre, each 1.5″ in diameter, $\frac{1}{8}''$ thick, and $\frac{3}{8}''$ wide. These are separated from each other and from the sphere by means of three brass rods $\frac{1}{16}''$ in diameter, which are tipped with fibre where they come in contact with the sphere, thus preventing local heating. The two circulating fans, one on each side of the heating coil, are mounted on a shaft of steel which runs in brass bearings mounted on the top of the rings of the heating coil and passing through the sphere in a bearing of wood fibre.

The shaft terminates just outside the sphere in a piece of fibre 3″ long, connected to the driving motor by means of a brass rod. This prevents undue conduction of heat from the interior of the sphere. The leads to the heating coil are rectangular iron wires passing through the sphere in the same plug as the wires to the inside thermo-electric junctions. The current and voltage are measured by an ammeter and voltmeter.

The sphere thus arranged is suspended in a bath kept at a uniform temperature. The bath is contained in two galvanized iron tanks. The outer tank is 30″ in diameter and 30″ high, surrounded and covered by a 2″ layer of hair felt to prevent undue radiation. The inner tank is 15″ in diameter and 22″ high, supported on the bottom of the larger by three iron supports 3″ high. The bottom is perforated with a large number of holes to allow free circulation of the oil. The sphere is supported at the centre of this tank on three wood fibre points, which are held in position by brass rods hung from the top.

To provide a means for circulating the oil in the bath, two steel shafts are mounted on diametrically opposite sides of the largest tank. Each shaft carries near its centre a fan having four blades 6″ in diameter.

One shaft is connected by a chain to gearing on a shaft in the centre of the small tank. This shaft carries a fan 12″ in diameter, which forces the oil up or down the inner tank. On the inside of the inner vessel are three projecting vanes, which break up the otherwise regularly circular motion of the liquid.

The fans are driven by a motor so arranged that the direction and speed of rotation can be changed. A special distilled petroleum oil was finally selected for the bath. The temperature of the oil is maintained constant by cold water flowing through a coil of lead pipe surrounding the inner tank. This is connected to a supply tank, thus insuring a constant temperature. It is also connected directly to the water mains and steam pipes, in order to provide a means for rapidly changing the temperature.

The temperature of the bath can be regulated by hand to give a constancy of 0.01°C. The temperature is observed by a thermometer read with a telescope.

Calibration Apparatus.

In order to determine the relation existing between the difference of temperature of the inside and outside junctions, and the corresponding E. M. F., the two hemispheres are removed from the apparatus and maintained at different known temperatures, while metallic contact is obtained between them by a piece of the same iron as the sphere.

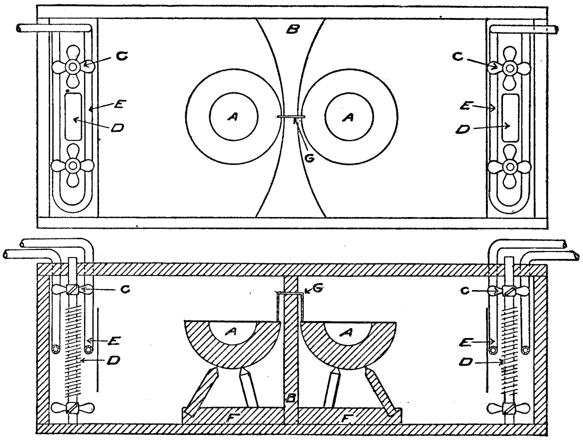

Figure 2.

The calibration tank (Figure 2) is a box 12″ × 24″ × 10″ deep lined with tin and separated into two compartments by a double tin partition, the space being filled with asbestos to prevent conduction of heat from one to the other.

Each compartment is provided with two fans to agitate the liquid, an electric heating coil, and a coil of lead pipe through which steam or cold water can be forced. Thus each compartment can be maintained at any desired temperature.

One hemisphere is placed on an insulating stand in each part of the calibration tank. These are connected by a small piece of iron from the original casting in the form of a U $\frac{1}{32}''$ in cross-section, each leg 1″ long and the base $1\frac{1}{2}''$ long. Each end of this is driven into a small hole in the iron of the hemisphere, thus insuring perfect metallic contact.

The lead wires from each hemisphere are bound together, and their ends inserted in separate holes on the wood-fibre block used for the terminals in taking measurements.

The following procedure is used in making the calibration. With the baths at the same temperature, tests are made to determine the existence of any outside E. M. F. The temperatures are then adjusted and the electromotive force determined. Next the temperatures are reversed and the electromotive force again determined.

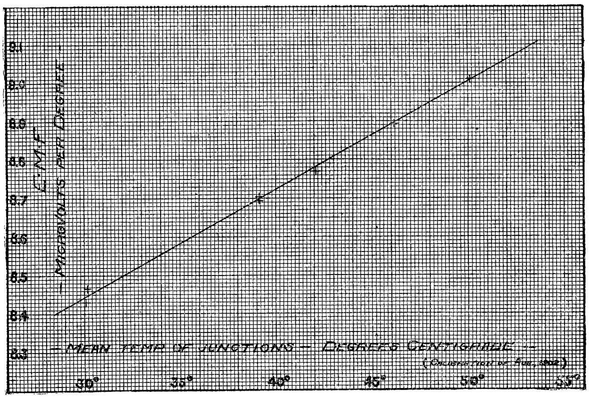

FIGURE 3.

The E. M. F. at the contact of the U piece and the hemispheres was at first very large, due to the fact that the U piece was simply pressed down on the iron, but after the small holes were made in the sphere and the U piece was driven in place, it was impossible to detect any extraneous E. M. F.

The following curve shows the results of the calibration as carried out in August, 1902.

The method of calibration of course assumes that the metal employed is of uniform thermo-electric properties, and so is applicable in strictness only to pure metals.

In computing results from the curves, the E. M. F. is taken at the temperature of the lower junction and the difference of temperature computed; then the E. M. F. of the mean temperature thus obtained is used to again determine the difference of temperature. This method of approximation is carried out until the difference of temperature obtained on successive trials is the same.

The thickness and diameter of the sphere were carefully measured before it was electroplated by special micrometer calipers.

The following results show the mean of thirty-six measurements.

Thickness, 1.4327 inches; Diameter, 6.0022 inches.

METHOD OF TAKING READINGS.

The circulating fans on the interior of the sphere and the agitating fans in the bath are first set in motion. Then the different junctions are connected to the galvanometer in order to locate any outside E. M. F., if such exists. The current is now turned on the heating coil and the flow of water through the cooling coil adjusted until the temperature of the bath remains constant. Meanwhile the galvanometer is calibrated as follows: The galvanometer is shunted across a standard ohm which is in series with a large resistance and storage cell. The resistance in the storage cell circuit is varied until the desired deflection is obtained (this being determined by the difference of temperature at which the run is to be made). The E. M. F. of the storage cell is at once obtained by the Poggendorf method, using a standard Carhart-Clark cell. When the temperatures of the outside of the sphere and bath have become constant, the terminals of the galvanometer are connected to junction No. 1. As soon as the deflection is constant the readings of the galvanometer, ammeter, voltmeter, and thermometer in bath are taken, also reading of thermometer in bath with nickel-iron junction, giving the temperature of the outside junction. The galvanometer is then reversed on No. 1 and the readings again taken.

The same method is followed on each junction, and then the whole series repeated four times, after which the galvanometer is again calibrated.

RESULTS.

The following results show the mean of four series of readings on each junction; i. e., 29.633 is the mean deflection on the four junctions, while 6.472 and 89.55 are the average amperes and volts during the run. This is a typical set of readings.

MAY 14, 1898.

Deflection.	E. M. F. of Junction.	Amperes.	Volts.
29.71		6.46	89.4
29.63		6.45	89.2
29.41		6.48	89.6
29.78		6.50	90.0
29.633	9.12 micro-volts	6.472	89.55
Corrected values		6.538	89.29
Difference of temperature, 10.46°. Value of K, 1281 at 39.50°.			

SUMMARY OF RESULTS.

Values of K:

April 14, 1898 . . .	.1273	at	43.7°
" 14, " . . .	.1267	"	43.3°
May 14, " . . .	.1281	"	39.5°
June 24, " . . .	.1281	"	39.8°
" 28, " . . .	.1259	"	43.2°
" 28, " . . .	.1254	"	43.2°
Mean . . .	.1269		
A. D. . . .	.0004		

There are certain errors which enter into these results which will be eliminated or corrected in subsequent experiments; namely, conduction through holes cut for lead wires, etc., variation of current and voltage, heat generated by rotation of fans on interior of sphere, uncertainty of galvanometer readings due to lack of sensitiveness of the instrument, lack of homogeneity in the shell.

Cast iron was used because it could be obtained and prepared with facility for the experiments which were designed as a test for the capabilities of the method, which is to be applied to the determination of the conductivity of pure metals.

ROGERS LABORATORY OF PHYSICS.
May, 1905.